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Cassini Orbit Determination from Launch to the First Venus Flyby

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The Cassini Orbiter/Huygens Probe was launched aboard a Titan IVB/Centaur launch vehicle on October 15, 1997. Before arriving at Saturn in July 2004, the spacecraft will achieve gravity assists from two Venus flybys, an Earth flyby, and a Jupiter flyby. Upon arrival at Saturn, the Huygens Probe will separate from the orbiter and descend through Titan's atmosphere, landing on the surface. The Orbiter will begin a four year tour of the Saturnian planetary system, with multiple close encounters of Titan and several encounters with the smaller satellites. This paper addresses orbit determination conducted between launch and the first Venus encounter, occurring on April 26, 1998.

Orbit determination during the Launch to Venus 1 leg is necessary to maintain the spacecraft on its nominal trajectory. Three trajectory correction maneuvers have been planned prior to the Venus flyby and a fourth is planned after the Venus flyby to correct significant deviations from the nominal trajectory. Accurate orbit determination allows spacecraft propellant to be used efficiently and, since the spacecraft will be flying only 340 km above the surface of Venus (160 km above an atmospheric level deemed dangerous to the spacecraft), allows safe navigation past Venus.

Orbit determination during this leg of the Cassini mission may be characterized by refining estimates of the spacecraft state, acceleration, and any velocity changes (ΔV's) via *a priori* information, telemetry, and radiometric data analysis. The accuracy of these refinements depends upon the geometry of the trajectory and the quality and quantity of radiometric data measurements. Many of these improved models will allow the spacecraft to be navigated more efficiently upon approach to the second Venus encounter on June 24, 1999.

A measure of the total spacecraft acceleration has been improved by estimating three distinct accelerations. The estimated accelerations are caused by outgassing, asymmetric radiation by the radio-isotope thermal electric generators (RTGs), and solar pressure. Outgassing effects were modeled as an exponentially decreasing acceleration with a time constant on the order of 20 - 50 days. Asymmetric RTG radiation effects were also modeled as an exponential acceleration, but with a time constant of nearly 127 years, making them effectively a constant over the short six month interval analyzed here. Solar pressure was divided into two components, which are both inversely proportional to the square of the spacecraft-sun range. The first component models the solar pressure force accelerating the spacecraft away from the sun. The second component models averaged uncoupled thruster pulsing necessary to maintain the spacecraft radial axis (-Z axis) to within a 2.5 degree cone angle from the sun. Telemetry returned in the form of thruster on-time has yielded a preliminary indication that these thruster firings are countering torques induced by solar pressure and are directed opposite to and have a magnitude roughly equal to 10% of the acceleration from direct solar pressure.

Trajectory geometry relative to the Earth and the sun made it difficult to separate and estimate these accelerations for the first few months after launch. Figure 1 shows that the spacecraft heliocentric range for the first 40 - 50 days remained around 1 AU. Errors in either the RTG radiation or the solar pressure acceleration during this period gave a similar signature in the radiometric data used to estimate these model's coefficients. Additionally, the spacecraft was trailing the Earth during this time so that accelerations directed radially from the sun were not directly observable. Figure 2 shows that the spacecraft geocentric declination was within 5 degrees of zero declination for most of the first 100 days. Many previous papers have demonstrated the limitations of Doppler data at low declinations[1,2]. After approximately mid-January 1998, the geometry became more favorable, allowing a more accurate estimation of each of these accelerations.

Several ΔV's are modeled and estimated, most notably TCM's 1, 2, 3, and 4. Nominal and reconstructed values will be presented along with the associated uncertainties. Reconstructed TCM's allow the spacecraft thrusters to be calibrated so that future trajectory correction maneuvers will be more efficient.

Acquisition of X-band Doppler and range data have enabled estimation of these various dynamic orbital parameters. A discussion of the quality and quantity of radiometric data will be presented. Additionally, several successful three-way range tests have been conducted in preparation for a period of time shortly after the first Venus flyby when it is expected that the signal to noise ratio from the 34 meter antennae will be to low to acquire two-way range from these stations. The DSN 70 meter stations do not currently have a capability to uplink an X-band signal. During this time, 34 m stations will uplink and, a round trip light time later, 70 m stations will receive the carrier signal with range modulation.

Finally, conclusions concerning orbit determination performance will be presented. Discussion will center primarily around orbit solutions made in support of TCM design and reconstruction. These solutions and their associated uncertainties will be compared with the best determined spacecraft orbit as reconstructed from a radiometric data arc extending through the first Venus flyby. Solutions using long data arcs shall be compared to solutions using short arcs. Other investigations that will be discussed include sensitivities to range and Doppler data weights and variations in orbit determination filter constraints.

Acknowledgments

The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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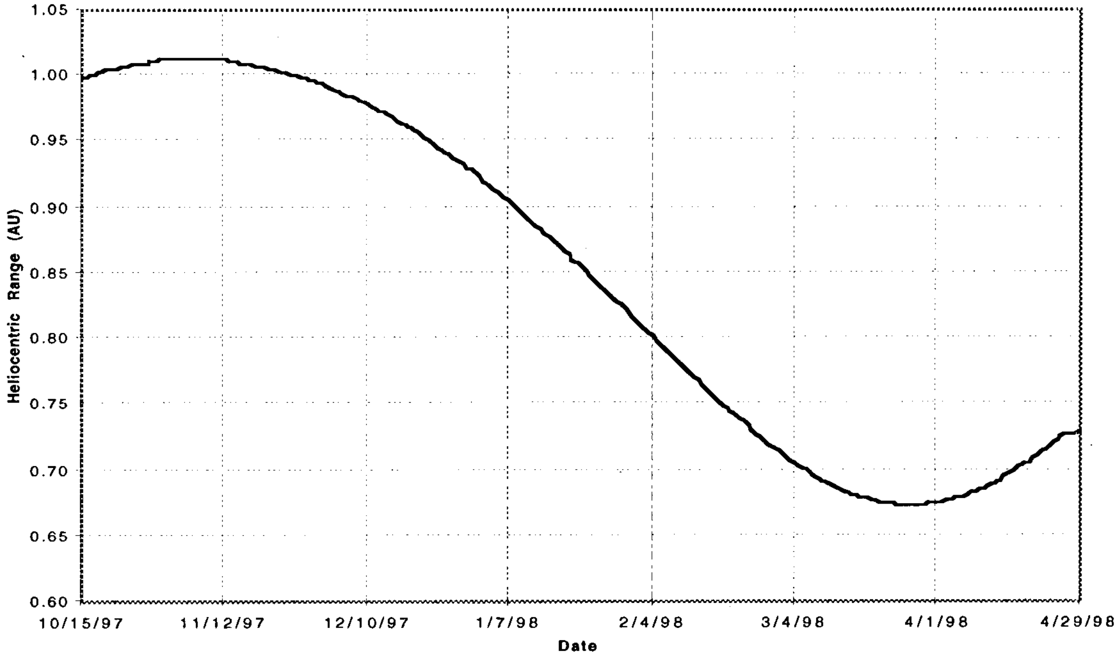

Figure 1. Spacecraft heliocentric range from launch to first Venus closest approach.

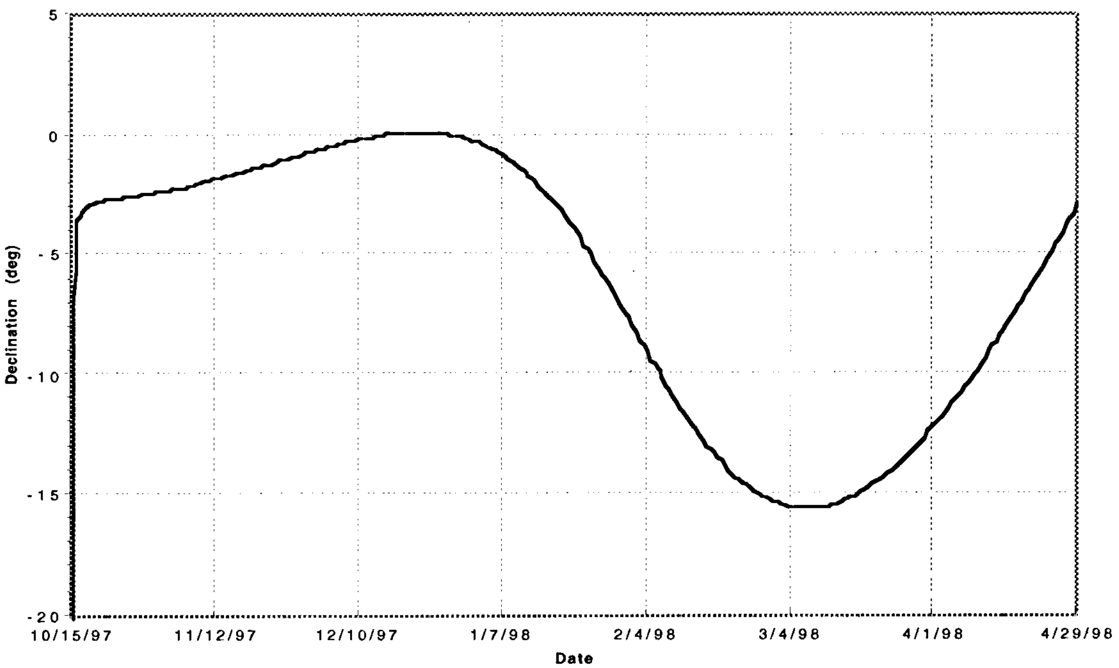

Figure 2. Spacecraft geocentric declination from launch to first Venus closest approach.